Title: Inspiratory muscle warm-up does not improve cycling time-trial performance

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ABSTRACT

Purpose This study examined the effects of an active cycling warm-up, with and without the addition of an inspiratory muscle warm-up (IMW), on 10-km cycling time-trial performance. **Methods** Ten cyclists ($\dot{V}O_2$ max = 65±9 $mL \cdot kg^{-1} \cdot min^{-1}$) performed a habituation 10-km cycling time-trial and three further time-trials preceded by either no warm-up (CONT), a cycling specific warm-up (CYC) comprising three consecutive 5 min bouts at powers corresponding to 70, 80, and 90% of the gas exchange threshold, or a cycling specific warm-up preceded by an IMW (CYC+IMW) comprising two sets of 30 inspiratory efforts against a pressure-threshold load of 40% maximal inspiratory pressure (MIP). The cycling warm-up was followed by 2 min rest before the start of the time-trial. **Results** Time-trial performance times during CYC (14.75±0.79 min) and CYC+IMW (14.70±0.75 min) were not different, although both were faster than CONT (14.99±0.90 min) (P<0.05). Throughout the time-trial physiological (minute ventilation, breathing pattern, pulmonary gas exchange, heart rate, blood lactate concentration and pH) and perceptual (limb discomfort and dyspnoea) responses were not different between CYC and CYC+IMW. Baseline MIP during CONT and CYC was 151±31 and 156±39 cmH_2O, respectively, and was unchanged following the time-trial. MIP increased by 8% after IMW (152±27 vs. 164±27 cmH_2O, P<0.05) and returned to baseline after the time-trial. **Conclusions** Improvements in 10-km cycling time-trial performance following an active cycling warm-up were not magnified by the addition of an IMW. Therefore, an appropriately designed active whole-body warm-up does adequately prepare the inspiratory muscles for cycling time-trials lasting approximately 15 min.

KEY WORDS: Respiratory muscle; pacing; prior exercise; perception

ABBREVIATIONS

CONT – control trial

CYC – cycling warm-up trial

CYC+IMW – cycling warm-up plus inspiratory muscle warm-up trial

IMW – inspiratory muscle warm-up

$[La^-]$ – lactate concentration

MIP – maximal inspiratory mouth pressure

PCO_2 – partial pressure of carbon dioxide

RER – respiratory exchange ratio

RPE – rating of perceived exertion

SpO_2 – arterial oxygen saturation

$\dot{V}_E$ – minute ventilation

$\dot{V}CO_2$ – carbon dioxide production

$\dot{V}O_2$ – oxygen uptake

$\dot{W}$ max – maximal power output

INTRODUCTION

Active whole body warm-up, or "priming", exercise is widely practiced to improve exercise performance. However, whilst the physiological effects of active warm-up exercise have received attention (Bailey et al. 2009; Bishop. 2003b; Jones et al. 2003), the performance benefits remain less clear, possibly because of inter-study differences in warm-up structure, criterion performance task, and participant training status (Bishop. 2003a; Sargeant and Dolan. 1987; Wittekind et al. 2012; Yaicharoen et al. 2012). An appropriately designed (i.e. according to the physical demands of the performance task) active warm-up improves short-term sprint (Sargeant and Dolan. 1987; Yaicharoen et al. 2012) and prolonged endurance exercise (Carter et al. 2005; Jones et al. 2003) performance. A limited number of studies have also examined the effect of active warm-up on simulated time-trial performance in competitive athletes, with ~1.0-2.8% improvements being observed for 3- and 4-km cycling and 800-m running performances (Hajoglou et al. 2005; Ingham et al. 2013; Palmer et al. 2009).

Although an active warm-up can positively impact on numerous physiological and perceptual responses to subsequent exercise (Bailey et al. 2009; Bishop. 2003b; Jones et al. 2003), typical warm-up protocols elicit only a low-to-moderate ventilatory demand and it has thus been suggested that the respiratory muscles may not be adequately "primed" for the criterion performance task (Volianitis et al. 1999). An inspiratory muscle warm-up (IMW) comprising inspiratory pressure-threshold loading increases inspiratory muscle strength and the maximum rate of inspiratory pressure development by ~10% (Hawkes et al. 2007; Lin et al. 2007; Lomax et al. 2011; Ross et al. 2007; Tong and Fu. 2006; Volianitis et al. 1999; Volianitis et al. 2001). Furthermore, the addition of an IMW to a whole-body active warm-up increased the distance completed during exhaustive intermittent running (Lin et al. 2007; Lomax et al. 2011; Tong and Fu. 2006) and all-out 6-min rowing (Volianitis et al. 2001)

exercise. These improvements have been associated with reduced dyspnoea (Lin et al. 2007; Lomax et al. 2011; Tong and Fu. 2006; Volianitis et al. 2001), blood lactate concentration ([La^-]) (Lin et al. 2007), and inspiratory muscle fatigue based on a smaller pre- to post-exercise decline in maximal inspiratory mouth pressure (MIP) (Volianitis et al. 2001).

However, validated whole body active warm-up protocols were not previously used nor were comparisons been made with a no warm-up condition. Assessing the magnitude of an IMW effect is therefore not possible since it is unknown whether the whole body active warm-up *per se* had a positive, negative or null effect on exercise performance. Furthermore, with one exception (Volianitis et al. 2001), studies have integrated the IMW (~10 min duration) either between successive active warm-up exercise bouts or between the active warm-up and the criterion performance task. The recovery duration after an active warm-up affects subsequent physiological responses and performance (Bailey et al. 2009; Bishop. 2003a; Burnley et al. 2006; Ferguson et al. 2010) and not standardising this period introduces an additional independent variable that further complicates interpretation of the literature.

Therefore, the aim of this study was to examine the effects of a validated cycling warm-up protocol, with and without the addition of an IMW, on 10-km cycling time-trial performance in competitive cyclists.

METHODS

Participants

Ten trained competitive road cyclists with normal pulmonary function (table 1) provided written informed consent to participate in the study. Testing took place during the racing season, and throughout the study participants were instructed to adhere to their habitual training regimen. Participants refrained from alcohol and strenuous exercise for 48 h, and caffeine for 24 h, before testing. Participants reported to the laboratory at least 2 h post-

prandial. The study was approved by the Nottingham Trent University Human Ethics Committee.

Experimental design

Participants attended the laboratory on five separate occasions, at a similar time of day, and separated by 1 week. During the first visit pulmonary function and MIP were assessed and participants performed a maximal incremental cycling test. During the subsequent four visits participants performed 10-km cycling time-trials, the first of which was a habituation trial that mimicked the control (CONT) trial (see below). The habituation trial was performed to minimise systematic error in the experimental time-trial tests (Stone et al. 2011). The three experimental time-trials were randomised and preceded by either no warm-up (CONT), a cycling specific warm-up (CYC), or a cycling specific warm-up plus an inspiratory muscle warm-up (CYC+IMW).

Equipment and measurements

Pulmonary function and MIP were assessed according to published guidelines (McConnell. 2007; Miller et al. 2005) using equipment and techniques described previously (Johnson et al. 2012; Mills et al. 2013). Briefly, pulmonary function was assessed using a pneumotachograph (Pneumotrac; Vitalograph, Buckinghamshire, UK) calibrated with a 3 L syringe. A hand-held mouth pressure meter (MicroRPM; CareFusion, Hampshire, UK) measured MIP, with manoeuvres initiated from residual volume and sustained for at least 1 s. Following baseline MIP, subsequent measures of MIP in each trial were based on four MIP manoeuvers. Following the recommendations of McConnell (McConnell. 2007) the highest recorded MIP was used for analysis. Cycling was performed on a Cyclus2 ergometer (Avantronic, Leipzig, Germany), which allows cyclists to use their own racing road bicycle. The axles that secure the front forks and the rear incorporate elastic suspension, which permits a more natural side-to-side movement. Ventilatory and pulmonary gas exchange

variables were measured using techniques and equipment described previously (Johnson et al. 2012; Mills et al. 2013). Briefly, participants wore a facemask (model 7940; Hans Rudolph, Missouri, USA) connected to a flow sensor (ZAN variable orifice pneumotach; Nspire Health, Oberthulba, Germany) that was calibrated using a 3 L syringe. Gas concentrations were measured using fast responding laser diode absorption spectroscopy sensors, which were calibrated using gases of known concentration (BOC, Guilford, UK), and ventilatory and pulmonary gas exchange variables were measured breath-by-breath (ZAN 600USB; Nspire Health, Oberthulba, Germany). Heart rate was measured using short-range telemetry (RS800CX; Polar, Kempele, Finland) and arterial oxygen saturation was estimated (SpO_2) using a finger pulse oximeter (Model 8500; Nonin Medical, Minnesota). Rating of perceived exertion (RPE) for limb discomfort and dyspnoea were obtained using Borg's modified CR10 scale (Borg. 1998). Arterialised venous blood was drawn from a heated dorsal hand vein via an indwelling 21-G cannula and analysed for blood [La^-] (Biosen C_line Sport; EKF Diagnostics, Barleben, Germany), PCO_2 and pH (ABL 520; Radiometer, Copenhagen, Denmark), which were corrected for changes in rectal temperature (1000 Series Squirrel; Grant Instruments, Cambridge, UK).

Maximal incremental cycling test

The maximal incremental cycling test comprised 3 min at 25 W followed by 25 W increments every minute until exhaustion (cycling cadence <60 rpm) (Hajoglou et al. 2005). Cycling cadence was self-selected by the participants and kept constant (group mean ± SD: 95 ± 5 rpm) until the limit of exercise tolerance approached, at which point cadence fell precipitously below 60 rpm, which defined the end of the test. The final power attained and the highest oxygen uptake ($\dot{V}O_2$) recorded over any 30 s period defined maximal power output ($\dot{W}$ max) and $\dot{V}O_2$ max, respectively. The gas exchange threshold was determined using the criteria of the point of departure from linearity of carbon dioxide production

($\dot{V}CO_2$) plotted against $\dot{V}O_2$ (V-slope method), and the point where $\dot{V}_E / \dot{V}O_2$ (where $\dot{V}_E$ is minute ventilation) increased without a concomitant increase in $\dot{V}_E / \dot{V}CO_2$ (Hajoglou et al. 2005; Lucia et al. 2003). The gas exchange threshold was detected by two independent observers. If there was any disagreement then a third investigator would have been consulted; however, on no occasion was this necessary.

10-km cycling time-trial tests

Following baseline measurements, including heart rate, blood sampling and MIP, the duration of the subsequent period prior to the time-trial was standardised at 30 min. During the first 8 min participants either remained seated at rest (CONT and CYC) or performed, using a pressure-threshold loading device (POWERbreathe®, 1st Series Generation, Gaiam, UK), an IMW (CYC+IMW) comprising two sets of 30 maximal inspiratory efforts, separated by 30 s, at an intensity of 40% baseline MIP (Lin et al. 2007; Tong and Fu. 2006; Volianitis et al. 2001). Inspiratory efforts were initiated from residual volume and participants strove to maximise tidal volume. Volianitis et al. (Volianitis et al. 2001) deployed an IMW before a whole-body warm-up and thus ~30 min before the rowing time-trial. Therefore, the IMW in the present study was also performed prior to the cycling warm-up and thus 22 min before the time-trial. During the subsequent 3 min MIP was re-evaluated. Participants then mounted their bicycle and either remained seated at rest for 19 min (CONT) or rested for 2 min and then performed a 15 min cycling warm-up (CYC and CYC+IMW). The cycling warm-up comprised three consecutive 5 min segments at powers corresponding to 70, 80, and 90% of the gas exchange threshold, followed by 2 min rest before the start of the time-trial (Hajoglou et al. 2005). Blood samples were taken, and heart rate and perceptual responses were measured, at the end of each 5 min segment of the warm-up period and every 2.5 km of the time-trial from 0-10 km inclusive. Ventilatory and pulmonary gas exchange variables were averaged over the final 2 min of each 5 min segment of the warm-up period, over the final

minute preceding the onset of the time-trial (i.e. defining 0 km), and over every 0.5 km of the time-trial. During the time-trial participants could continuously view both distance completed and momentary velocity, and the only instruction given was to complete the time-trial in the shortest time possible (Hajoglou et al. 2005). After the time-trial participants immediately dismounted their bicycle and during the subsequent 3 min MIP was re-evaluated.

A placebo IMW was not performed because two sets of 30 forced, but non-loaded, inspiratory efforts has been shown to increase MIP (+9%) and the diaphragm motor-evoked potential (+22%) in response to magnetic phrenic nerve stimulation (Ross et al. 2007).

Data analysis

Data were analysed using two-way repeated measures ANOVA and Tukey's post-hoc test was used to identify statistically significant differences between pairs of mean values. Statistical significance was set at $P < 0.05$. Results are presented as mean ± SD unless otherwise indicated.

RESULTS

10-km cycling time-trial performance

Cycling time-trial performance time during CYC (14.75 ± 0.79 min) and CYC+IMW (14.70 ± 0.75 min) were not different, although both were faster than CONT (14.99 ± 0.90 min) ($P < 0.05$). The faster times during CYC and CYC+IMW resulted from a higher cycling power output during the first 4-5-km, after which power output was similar between trials (figure 1). All time-trials were characterised by an end spurt during the final kilometre.

Maximal inspiratory mouth pressure

Baseline MIP was not different between CONT (151 ± 31 cmH_2O), CYC (156 ± 39 cmH_2O), and CYC+IMW (152 ± 27 cmH_2O). MIP was unchanged following the subsequent 8 min of rest during CONT (150 ± 34 cmH_2O) and CYC (153 ± 35 cmH_2O), but was increased by 8%

after the IMW (164 ± 27 cmH_2O) ($P < 0.05$). The MIP after the time-trial was not different from baseline during CONT (149 ± 39 cmH_2O), CYC (148 ± 39 cmH_2O) and CYC+IMW (153 ± 39 cmH_2O).

Ventilatory responses

Throughout the warm-up period and the time-trial duty cycle was not different between trials (figure 2). The $\dot{V}_{E,}$ tidal volume and breathing frequency were higher during the warm-up period of CYC and CYC+IMW compared to CONT. Furthermore, except for breathing frequency, these responses were higher at various time points during the time-trial. Throughout the warm-up period and the time-trial ventilatory responses were not different between CYC and CYC+IMW (figure 2).

Pulmonary gas exchange, heart rate, arterial oxygen saturation, and rectal temperature

The $\dot{V}O_{2,}$ and $\dot{V}CO_2$ were higher during the warm-up period, and at the start of the time-trial, during CYC and CYC+IMW compared to CONT (figure 3). These variables also remained higher during the initial 4-6 km of the time-trial, after which they were not different between trials. Changes in heart rate, SpO_2 and rectal temperature were not different between CYC and CYC+IMW (figure 3). Throughout the warm-up period and the time-trial heart rate was higher during CYC and CYC+IMW compared to CONT ($P < 0.01$). After 10 and 15 min of the warm-up period, and at the start of the time-trial, SpO_2 was lower during CYC and CYC+IMW compared to CONT ($P < 0.01$). Though most of the cyclists in the present study demonstrated a modest (2-3%) reduction in SpO_2 during the cycling warm-up, one participant consistently experienced a SpO_2 <90%. This participant also experienced marked increases in PCO_2 (sometimes reaching 60 mm Hg), indicative of inadequate hyperventilation. Indeed, desaturation during submaximal (40% $\dot{V}O_2$ max) exercise has been reported previously in trained cyclists and is attributed to an inadequate hyperventilatory response (Rice et al. 1999). After 15 min of the warm-up period rectal temperature was higher during CYC+IMW

compared to CONT ($P < 0.05$). Rectal temperature was higher throughout the time-trial during CYC and CYC+IMW compared to CONT ($P < 0.01$).

Blood [La^-], pH and PCO_2

Throughout the warm-up period and the time-trial changes in blood [La^-], pH and PCO_2 were not different between CYC and CYC+IMW (figure 4). During the warm-up period blood [La^-] was approximately 0.50 $mmol \cdot L^{-1}$ higher during CYC and CYC+IMW compared to CONT ($P < 0.05$). Blood [La^-] and pH during the time-trial were not different between trials. After 15 min of the warm-up period and from 0-7.5 km of the time-trial, PCO_2 was lower during CYC and CYC+IMW compared to CONT ($P < 0.01$).

Perceptual responses

Throughout the warm-up period and the time-trial perceptual responses were not different between CYC and CYC+IMW (figure 5). Throughout the warm-up period RPE and dyspnoea were higher during CYC and CYC+IMW compared to CONT ($P < 0.01$), and such differences were also observed at various time points during the time-trial.

DISCUSSION

The main finding of the present study was that 10-km cycling time-trial performance was improved after a specific cycling warm-up, but performance was not further improved with the addition of an IMW.

The efficacy of an active warm-up is largely dependent on its structure, which should be designed according to the physical demands of the performance task (Bishop. 2003a). The warm-up protocol used in the present study elicited a $\dot{V}O_2$ response that progressively increased from ~60% to ~70% $\dot{V}O_2max$ and which remained elevated above rest at the onset of the time-trial. Furthermore, the active warm-up was unlikely to have caused significant muscle fatigue due to metabolite accumulation since blood pH did not change and [La^-]

increased only slightly. According to Bishop (Bishop. 2003a) these two observations are indicative of an optimal warm-up protocol. The faster time-trial time during CYC compared to CONT is consistent with the findings of Hajoglou et al. (Hajoglou et al. 2005) who reported improvements in 3-km cycling time-trial performance after an identical warm-up protocol. The mechanism by which warm-up improves performance is likely to be multifaceted and possibly include: increased nerve conduction velocity, faster $\dot{V}O_2$ kinetics due to reduced oxidative metabolic inertia, increased aerobic contribution, and reduced muscle and joint stiffness (Bishop. 2003b; Hajoglou et al. 2005; Ingham et al. 2013; Palmer et al. 2009). Altered metabolic responses could explain the observed change from a negative (CON) to a J-shaped (CYC and CYC+IMW) pacing strategy. The former may reduce the rate of carbohydrate depletion, minimise excessive $\dot{V}O_2$, and/or reduce the accumulation of fatigue-related metabolites during the initial stages of the performance task (Abbiss and Laursen 2008). However, an active warm-up may elicit such changes prior to the performance task, thereby affecting the pacing strategy. In addition, an active warm-up might improve time-trial performance by changing, or increasing tolerance to, the evoked perceptual responses, although changes in physiological and perceptual responses are unlikely to be mutually exclusive (see below). To our knowledge this study is the first to examine the effects of warm-up on perceptual responses during time-trial exercise. Interestingly, when an active warm-up preceded time-trial exercise perceptual responses were *higher* and concomitant with higher cycling powers and greater change in markers of physical exertion. It is unclear why the cyclists did not exercise at a power output during CONT sufficient to elicit the same perceptual response as in CYC and CYC+IMW. Tucker (Tucker. 2009) suggests that work-rate during self-paced exercise is regulated according to a combination of afferent feedback, which generates the conscious perception of effort, and an anticipatory component, which generates the “expected” perception of effort or “template”,

against which the conscious effort is compared. The perceptual "template" for the time-trial may have therefore been modified by the active warm-up. Specifically, the "acceptable" level of effort perception was increased thereby increasing tolerance to afferent feedback, as indicated by the higher heart rate, rectal temperature, and ventilatory and pulmonary gas exchange responses during CYC and CYC+IMW compared to CONT. Though the cause of this modification remains unknown, it may have resulted from increased motivation and arousal elicited by the warm-up (Tucker. 2009).

The present study demonstrates, however, that adding an IMW to an ergogenic active warm-up provides no further benefit to exercise performance. This finding differs from previous IMW studies demonstrating improvements in distance completed during exhaustive intermittent running (Lin et al. 2007; Lomax et al. 2011; Tong and Fu. 2006) and all-out 6-min rowing (Volianitis et al. 2001). Although differences in exercise modality may partly explain these discrepancies, the findings of previous studies remain inconclusive because a validated active warm-up was not used nor were the effects of the warm-up *per se* evaluated. The duration of the period prior to the criterion performance task was also not standardised (Cheng et al. 2013; Lin et al. 2007; Lomax et al. 2011; Tong and Fu. 2006; Volianitis et al. 2001), which may have influenced subsequent physiological and perceptual responses and performance (Bailey et al. 2009; Bishop. 2003a; Burnley et al. 2006; Ferguson et al. 2010). Previous IMW studies also include a 5-10 min period of stretching in the active warm-up, which may also impair subsequent exercise performance (Behm and Chaouachi. 2011). Finally, given that the self-paced active warm-up protocols adopted by highly trained experienced athletes are not always optimal (Ingham et al. 2013; Mandengue et al. 2005), it is possible that sub-optimal (possibly even detrimental) self-paced active warm-up protocols were performed by the recreationally active participants in some IMW studies (Lin et al. 2007; Lomax et al. 2011; Tong and Fu. 2006). We controlled for the aforementioned

confounding variables and demonstrated no further performance benefits when an IMW is added to an ergogenic active warm-up.

Whether IMW efficacy is dependent upon its proximity to the criterion performance task is unknown. In the present study the IMW was performed before the cycling warm-up and thus 22 min before the time-trial. This approach was based on the work of Volianitis et al. (Volianitis et al. 2001) who performed the IMW before a whole-body rowing-specific warm-up and thus ~30 min before a 6 min rowing time-trial. Rowing time-trial performance was improved by 0.4% and dyspnoea and inspiratory muscle fatigue (defined as a fall in MIP) were reduced. It thus seems unlikely that the unchanged time-trial performance during CYC+IMW was due to an excessive interval between the IMW and the time-trial. Compared to cycling, however, rowing places additional demands on the inspiratory muscles (i.e. postural control and propulsive forces) (Shephard. 1998), and, the brevity of the criterion performance task used by Volianitis et al. (Volianitis et al. 2001) dictates that a higher exercise intensity was performed. These factors might explain these inter-study discrepancies.

The 8% increase in MIP after the IMW is consistent with previous studies (Hawkes et al. 2007; Lin et al. 2007; Lomax et al. 2011; Ross et al. 2007; Tong and Fu. 2006; Volianitis et al. 1999; Volianitis et al. 2001) and similar increases have also been observed in the maximal rate of inspiratory pressure development (Lin et al. 2007; Tong and Fu. 2006). These changes have been attributed to improved coordination / synergy of the inspiratory muscles and / or increased voluntary activation of the inspiratory muscles (Hawkes et al. 2007; Ross et al. 2007). It is suggested that IMW-mediated increases in MIP reduce the fractional utilisation of maximum tension generated with each inspiration, thereby reducing dyspnoea and increasing exercise tolerance (Lin et al. 2007; Tong and Fu. 2006; Volianitis et al. 2001). Interestingly, in two separate studies Tong et al. (Tong and Fu. 2006; Tong et al. 2008) report a two-fold greater reduction in dyspnoea during the Yo-Yo test after an IMW (-

22%) compared to 6-weeks inspiratory muscle training (-11%), despite a much smaller increase in MIP after IMW (9 vs. 32%). Comparable improvements in Yo-Yo test running performance were also observed following an IMW (13-19%) and inspiratory muscle training (16%). It seems inconceivable that any short-term benefits elicited by an IMW would approach / surpass the benefits that result from the morphological adaptations that probably occur in the inspiratory muscles after inspiratory muscle training (Brown et al. 2010; Brown et al. 2012; Mills et al. 2013) and, therefore, it is difficult to resolve why comparable ergogenic benefits were observed. The notion that IMW-mediated increases in MIP elicit reductions in dyspnoea can also be questioned based on reduced dyspnoea persisting >15 min after the IMW was performed (Lin et al. 2007; Tong and Fu. 2006; Volianitis et al. 2001), which is the maximum time required for restoration of the neurophysiological changes, and associated increase in MIP, induced by an IMW (Ross et al. 2007). Indeed, the notion that a transient IMW-mediated increase in MIP reduces dyspnoea was not supported by our observations during the fixed work-rate active cycling warm-up, which began 2 min after the observed 8% increase in MIP.

In summary, 10-km cycling time-trial performance was unaffected by the addition of an IMW to a whole-body active warm-up. This observation suggests that an appropriately designed whole-body active warm-up does adequately prepare the inspiratory muscles for cycling time-trials lasting ~15 min.

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Table 1 Participant characteristics. Mean ± SD.

Variable	
Age (yr)	32 ± 9
Height (cm)	180 ± 4
Body mass (kg)	76 ± 9
FVC (L)	5.95 ± 0.71
FEV_1 (L)	4.76 ± 0.56
FEV_1/FVC (%)	81 ± 5
MVV_{10} ($L \cdot min^{-1}$)	208 ± 23
MIP (cmH_2O)	148 ± 32 (109 ± 9)
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	4.91 ± 0.80
$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	65 ± 9

FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 s; MVV_{10}, maximum voluntary ventilation in 10 s; MIP, maximal inspiratory mouth pressure; $\dot{V}O_2max$, maximal oxygen consumption. Values in parenthesis represent percentage of predicted value (Wilson et al. 1984).

FIGURES

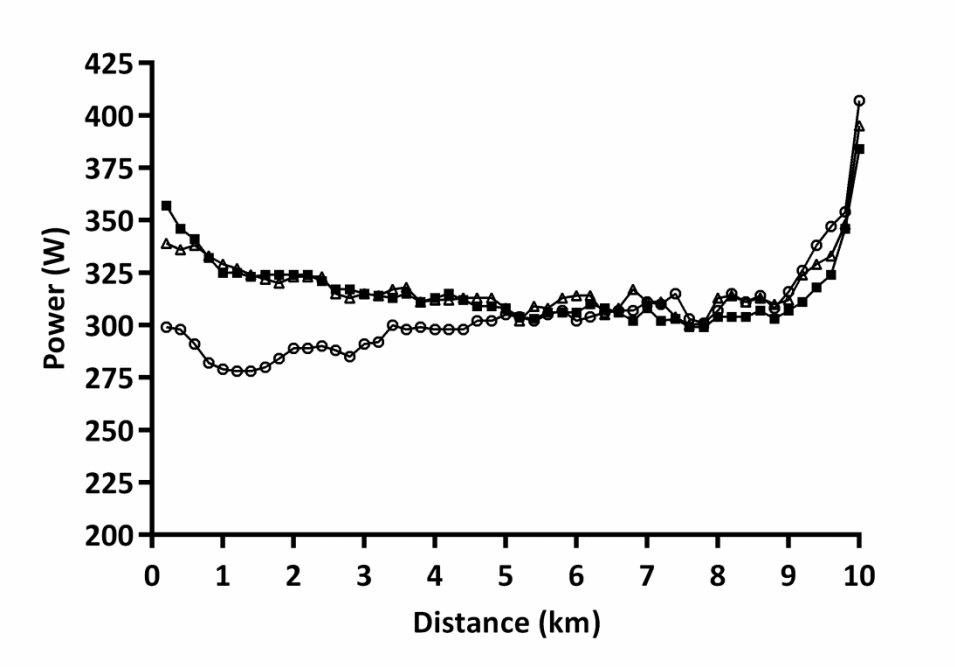

Figure 1 Power output during the 10-km time-trial for CONT (○), CYC (■), and CYC+IMW (∆). Data are mean with error bars omitted to enhance clarity.

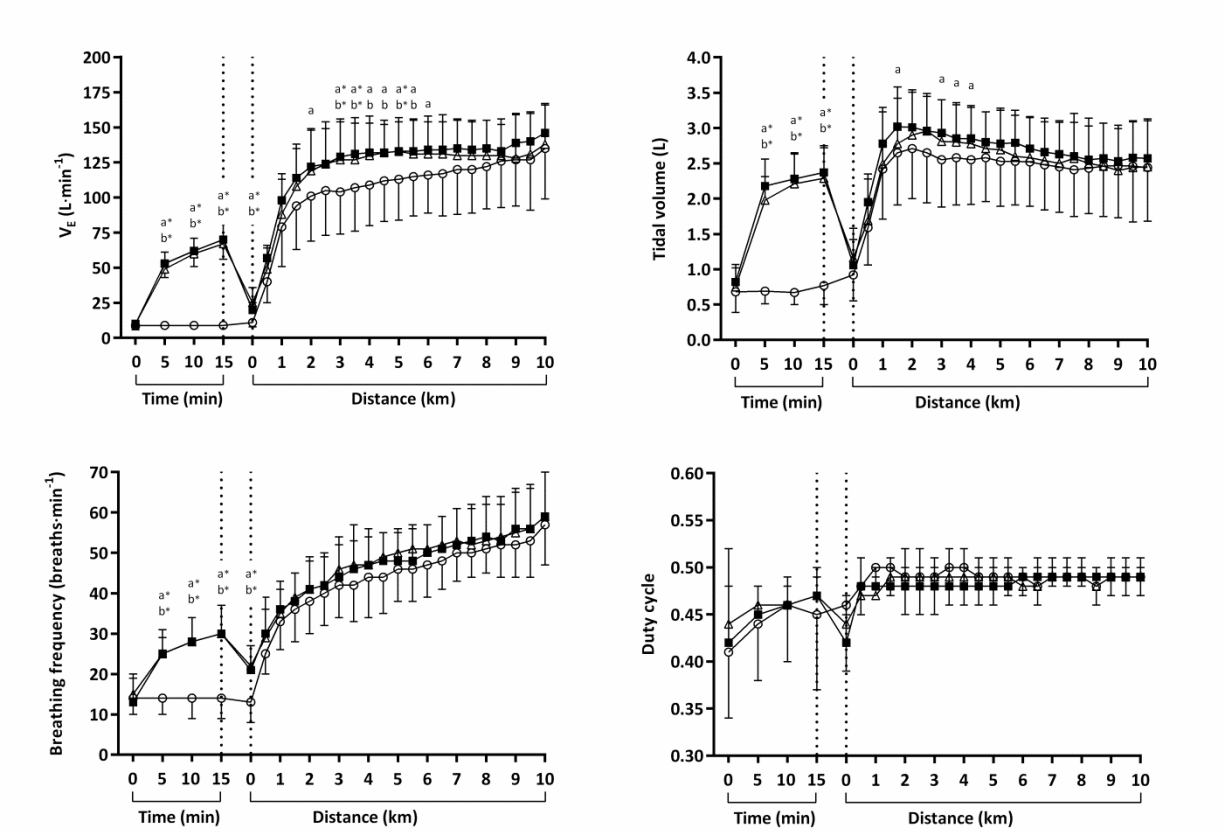

Figure 2 Ventilatory responses during the 15 min warm-up period and the 10-km time-trial for CONT (○), CYC (■), and CYC+IMW (Δ). Dashed vertical lines denote the 2 min intervening rest period between the warm-up period and the start of the time-trial. Data are mean ± SD. Significant difference between trials ($P < 0.05$): a, CONT vs. CYC; b, CONT vs. CYC+IMW. *, indicates $P < 0.01$.

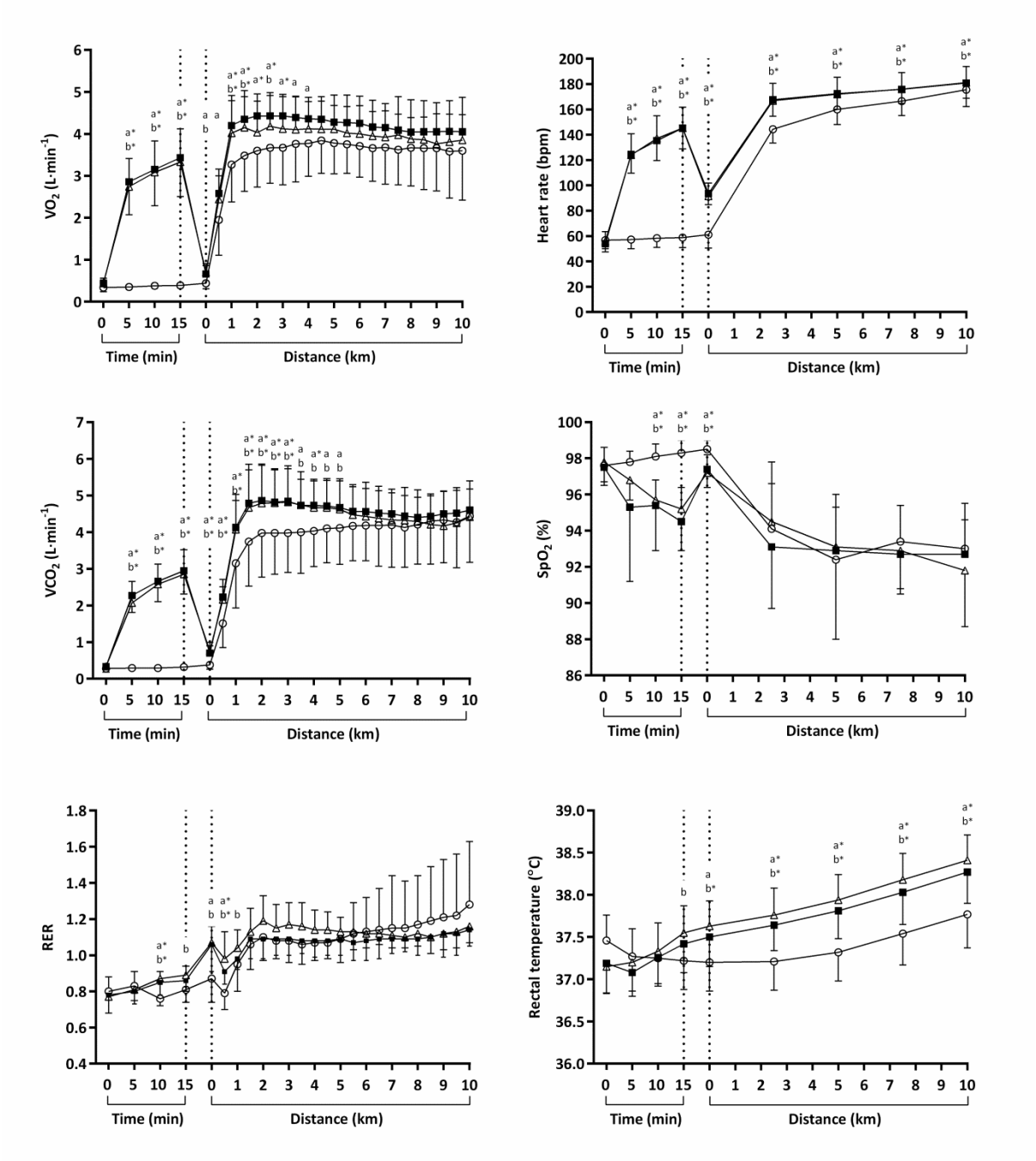

Figure 3 Pulmonary gas exchange, heart rate, arterial oxygen saturation (SpO_2) and rectal temperature during the 15 min warm-up period and the 10-km time-trial for CONT (○), CYC (■), and CYC+IMW (Δ). Dashed vertical lines denote the 2 min intervening rest period between the warm-up period and the start of the time-trial. Data are mean ± SD. Significant difference between trials ($P < 0.05$): a, CONT vs. CYC; b, CONT vs. CYC+IMW. *, indicates $P < 0.01$.

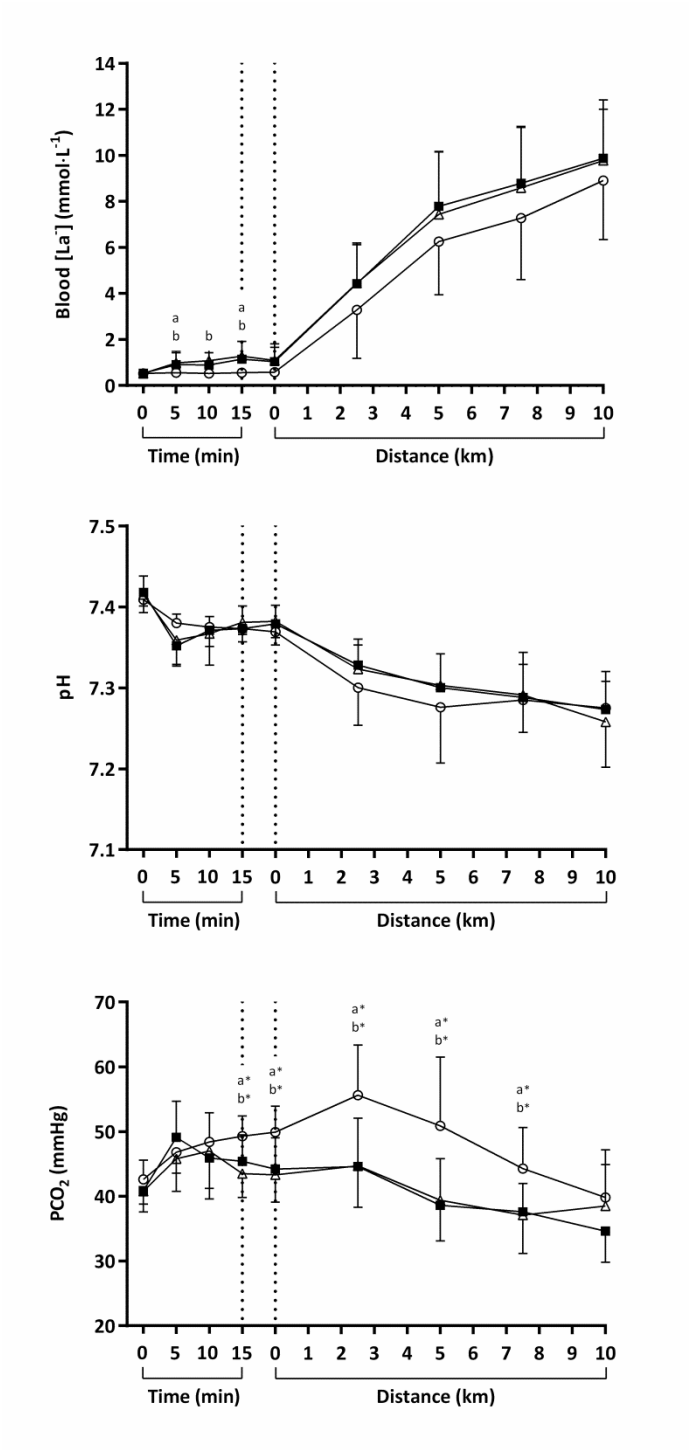

Figure 4 Blood [La^-], pH, and PCO_2 during the 15 min warm-up period and the 10-km time-trial for CONT (○), CYC (■), and CYC+IMW (∆). Dashed vertical lines denote the 2 min intervening rest period between the warm-up period and the start of the time-trial. Data are mean ± SD. Significant difference between trials ($P < 0.05$): a, CONT vs. CYC; b, CONT vs. CYC+IMW. *, indicates $P < 0.01$.

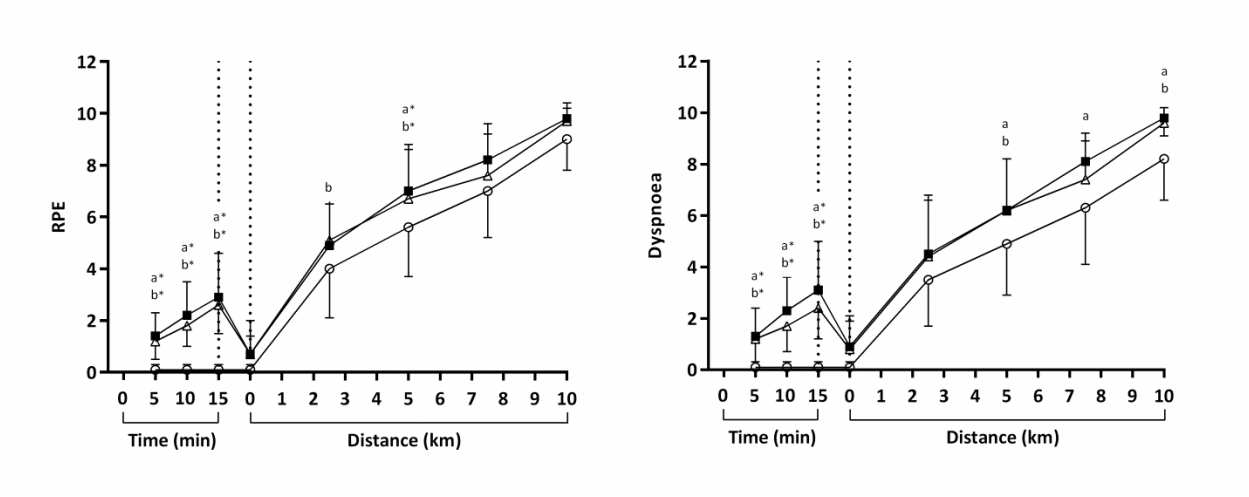

Figure 5 RPE and dyspnea during the 15 min warm-up period and the 10-km time-trial for CONT (○), CYC (■), and CYC+IMW (∆). Dashed vertical lines denote the 2 min intervening rest period between the warm-up period and the start of the time-trial. Data are mean ± SD. Significant difference between trials ($P < 0.05$): a, CONT vs. CYC; b, CONT vs. CYC+IMW. *, indicates $P < 0.01$.